NASA TECHNICAL MEMORANDUM

NASA TM X-2995

NASA TM X-2995

VENTING CHARACTERISTICS OF GASEOUS HELIUM AND NITROGEN DISCHARGING INTO A FREE STREAM AT MACH NUMBERS FROM 0.60 TO 1.57

by Albert L. Johns and Merle L. Jones

Lewis Research Center

Cleveland, Ohio 44135

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1974

1. Report No. TM X-2995	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle VENTING CHARACTERISTICS OF GASEOUS HELIUM AND NITROGEN DISCHARGING INTO A FREE STREAM AT MACH NUMBERS FROM 0.60 TO 1.57		5. Report Date APRIL 1974
		6. Performing Organization Code
7. Author(s) Albert L. Johns and Merle L. Jones		8. Performing Organization Report No. E-7698
		10. Work Unit No. 501-24
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

An experimental investigation was conducted in the Lewis Research Center 8- by 6-Foot Supersonic Wind Tunnel to compare the effects on discharge coefficient of venting gaseous helium and gaseous nitrogen into a free stream. The test was conducted from Mach 0.60 to 1.57 with the vent mounted in a flat plate. The plate was strut mounted to the tunnel ceiling and at a 0 angle of attack. The gases were discharged from a plenum chamber through a 2.54-centimeter (1.00-in.) diameter vent. The ratio of local static pressure to plenum pressure was varied from 0.51 to 0.975. The ratio of boundary-layer thickness to vent diameter varied from a maximum of 1.34 at Mach 0.60 to a minimum of 0.55 at Mach 1.37.

17. Key Words (Suggested by Author(s))		18. Distribution Statement	
Flow coefficient Helium venting Nitrogen venting Venting characteristics		Unclassified - unlimited CAT. 12	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 16	22. Price* $3.00

* For sale by the National Technical Information Service, Springfield, Virginia 22151

VENTING CHARACTERISTICS OF GASEOUS HELIUM AND NITROGEN DISCHARGING INTO A FREE STREAM AT MACH NUMBER FROM 0.60 TO 1.57

by Albert L. Johns and Merle L. Jones

Lewis Research Center

SUMMARY

An experimental program was conducted in the Lewis Research Center 8- by 6-Foot Supersonic Wind Tunnel to compare the effects on discharge coefficient of venting gaseous helium and gaseous nitrogen into the free stream. The test was conducted from Mach 0.60 to 1.57 with the vent mounted in a flat plate. The plate was strut mounted to the tunnel ceiling and at a 0 angle of attack. The gases were discharged from a plenum chamber through a 2.54-centimeter (1.00-in.) diameter vent.

The test was conducted to provide data for the design and analysis of the Titan/Centaur launch vehicle compartment vent system. The ratio of boundary-layer thickness to vent diameter varied from a maximum of 1.34 at Mach 0.60 to a minimum of 0.55 at Mach 1.37. The vent discharge coefficient decreased with increasing free-stream Mach number up to Mach 1.37 and then increased slightly. In most cases, the vent discharge coefficient for nitrogen was slightly higher than that for helium at the same local static-pressure to plenum-pressure ratio. But for practical application the differences in discharge coefficient were insignificant. In addition, the variation of discharge coefficient with jet to free-stream mass flow ratio indicated that the flow coefficient with helium was more sensitive to changes in mass flow ratio for the range studied.

INTRODUCTION

During ascent through the atmosphere, several compartments in the Titan/Centaur launch vehicle are vented overboard into the free stream. The venting during this portion of the flight must be controlled in such a way that the compartment walls are not exposed to excessive crush or burst pressures. In designing a vent system that will meet this requirement, consideration must be given to the phenomenon that occurs at the vent outlet when the vented gas impinges the air stream moving over the surface of the vehicle. The interaction of the exiting jet with the external flow creates a separated flow at the vent exit. This results in a local external pressure higher than that which would exist without the vent flow. Inasmuch as the vent flow rates are directly related to the pressures at the vent outlets, the need to include the effects of the exiting-jet - free-stream interaction in the vent system design is obvious.

Some work has been done to investigate this phenomenon using air as the vented gas (e.g., refs. 1 to 6). In a practical application of the results of the investigation, the increased external pressure, with resulting lower vent flow rates, is expressed in terms of a reduced vent flow coefficient. Because one of the vented compartments in the Titan/Centaur launch vehicle, the hydrogen tank/shroud annulus, contains gaseous helium, the present test was conducted to determine the difference, if any, in the effective flow coefficient when venting helium and nitrogen. Any differences can then be applied to the existing data for vented air. It is assumed that there are no differences in flow coefficients for air and nitrogen because of the similarity of physical constants between these two gases (ref. 7).

The test was conducted in the Lewis Research Center 8- by 6-Foot Supersonic Wind Tunnel over a range of Mach numbers varying from 0.60 to 1.57. The vent plenum was attached to the aft end of a boundary-layer plate which was strut mounted from the tunnel ceiling and at 0^{o} angle of attack. The gases were discharged through a 2.54-centimeter (1.00-in.) diameter vent located on the underside of the plate.

SYMBOLS

k	vent discharge coefficients based on ideal one-dimensional flow rate which assumes static pressure obtained from a point on plate surface ahead of vent
M_0	free-stream Mach number
p_l/p_0	local static to free-stream static pressure ratio
$p_{l,3}/P_P$	plenum pressure ratio; ratio of local static pressure on plate forward of vent and away from jet - free-stream interaction region to plenum pressure
r	mass flow ratio (jet to free stream); ratio of measured vent mass flow of air through stream tube at free-stream conditions with cross-sectional area equal to vent area
V_l/V_0	velocity ratio (local velocity to free-stream velocity)
x/d_v	pressure tap spacing ratio (axial distance from center of vent to vent diameter)
y	normal distance from plate surface

y/δ ratio of normal distance from plate surface to boundary-layer thickness

δ boundary-layer thickness; height of boundary layer where local velocity becomes 99 percent of free-stream velocity

δ^* displacement thickness; measure of deficiency in mass flow through boundary layer as result of stream having been slowed by friction

θ momentum thickness; thickness of free-stream flow necessary to make up deficiency in momentum flux within boundary layer

APPARATUS

The boundary-layer plate installation in the wind tunnel is shown in figure 1. The plate was strut mounted to the tunnel ceiling with the plenum chamber attached to the aft end (fig. 1(b)). Gaseous helium and nitrogen were supplied from trailers at high pressure and reduced through a series of regulators to the plenum chamber.

The plate was 172.72 centimeters (68.00 in.) long and 88.90 centimeters (35.00 in.) wide with a thickness of 2.54 centimeters (1.00 in.) (fig. 2(a)). The centerline of the vent was 114.30 centimeters (45.00 in.) from the leading edge of the plate. The boundary-layer rake was 114.30 centimeters (45.00 in.) from the leading edge and 16.51 centimeters (6.50 in.) from the plate centerline. Details of the plenum chamber are given in figure 2(b). Two baffle plates were located in the upper part of the plenum chamber to smooth the flow. The vent was 2.54 centimeters (1.00 in.) in diameter and 3.03 centimeters (1.20 in.) thick.

TEST FACILITY AND INSTRUMENTATION

A schematic view of the boundary-layer plate and plenum chamber installation in the wind tunnel is shown in figure 3. The plenum chamber was mounted to the aft section of the mounting strut and contained the gas supply line. The flow system schematic diagram is shown in figure 4. A venturi with a 3.495-centimeter (1.376-in.) maximum diameter and a 2.032-centimeter (0.80-in.) diameter throat was used to measure the gas flow. The two gases were in a parallel system upstream of the venturi; that is, from the venturi to the plenum chamber, the system was common to both gases.

Details of the plate instrumentation are shown in figure 5(a), and boundary-layer rake details are given in figure 5(b). The rake contained six probes and was 16.51 centimeters (6.50 in.) from the center of the plate. The vent was located at the same axial position as the rake but along the centerline of the plate. The internal instrumentation of the plenum and that in the vicinity of the vent are shown in figure 5(c). Pressure tap spacing is shown on the table in figure 5(c).

RESULTS AND DISCUSSION

The boundary-layer velocity profiles measured 114.30 centimeters (45.00 in.) from the leading edge of the plate and 16.51 centimeters (6.50 in.) from the centerline are shown in figure 6 over the Mach number range tested. The velocity profile was used to obtain the boundary-layer thickness, which is defined as the height at which the local velocity becomes 99 percent of the free-stream velocity. Nondimensionalized boundary-layer profiles are shown in figure 7. The boundary-layer, displacement, and momentum thicknesses are presented in figure 8 for the Mach number range tested. The ratio of boundary-layer thickness to vent diameter varied from a maximum of 1.34 at Mach 0.60 to a minimum of 0.55 at Mach 1.37.

A comparison of the effect of free-stream Mach number on the vent discharge coefficients for helium and nitrogen is presented in figure 9 at a plenum pressure ratio of 0.80. The discharge coefficient decreased with increasing Mach number up to $M_0 = 1.37$ for both gases. However, the boundary-layer thickness decreased concurrently over this Mach number range (fig. 8). A slight increase in discharge coefficient occurred beyond Mach 1.37.

The discharge coefficient for nitrogen was approximately 2 to 4 percent higher than helium over the Mach range tested.

Variation of vent discharge coefficients with the plenum pressure ratio is shown in figure 10 for the Mach number range investigated. The plenum pressure ratio $p_{l,3}/P_p$ is based on a static pressure located upstream of the vent and away from the interaction of the vented gas and the free stream to the plenum pressure. This static pressure is about equal to free-stream static pressure and is also free from local disturbances (to be discussed later). In general the discharge flow coefficient for nitrogen was slightly higher than that of helium but by an insignificant amount for practical application. The trend for both gases was a decreasing discharge coefficient with increasing plenum pressure ratio $p_{l,3}/P_p$.

The pressure distribution along the centerline of the plate, that is, upstream and downstream of the vent, are shown in figure 11. Data are shown for helium and nitrogen at selected plenum pressure ratios of 0.60 (fig. 11(a)) and 0.80 (fig. 11(b)). Data are also shown for no vent flow conditions to give a direct comparison of pressure deviations that are caused by the open vent. As expected, there is a rise in pressure upstream of the vent caused by the interaction of gas and free-stream flow. On the downstream side of the vent the pressure is considerably below p_0. A more detailed discussion of jet interaction is given in reference 8. The foregoing effects are dependent on the plenum pressure ratio (mass flow) as can be seen from the comparison of figure 11(a) and (b). The lower the plenum pressure ratio $p_{l,3}/P_p$ (higher mass flow), the more pronounced the compression (upstream) - expansion (downstream) region in the vicinity of the vent.

The plate pressure distributions 16.51 centimeters (6.50 in.) off the centerline of the plate are presented in figure 12 for no vent flow conditions. The data with vent flow showed no differences in pressure distributions. A localized disturbance (with respect to the direction of free-stream airflow) occurred on the plate from $M_0 = 1.00$ to 1.57. This disturbance affects the static pressure used in computing the plenum pressure ratio at $M_0 = 1.20$. At this Mach number the second pressure tap (from the leading edge of the plate) rather than the third pressure tap was used in the computation. At $M_0 = 1.37$ the disturbance is in the vicinity of the vent and probably had an effect on the discharge of gases.

Variation of vent discharge coefficients with jet to free-stream mass flow ratio is shown in figure 13. The free-stream mass was computed based on a stream tube area equivalent to that of the vent area. The mass flow ratio varied from 0.03 ($M_0 = 1.56$) to 0.95 ($M_0 = 0.60$). At low values of jet to free-stream mass flow ratio, the vent discharge coefficient increased rapidly for both gases. At the higher mass flow ratios this variation in discharge coefficient is not as pronounced. In addition, at the low values for mass flow ratio, the vent flow coefficient for helium was significantly higher than that of nitrogen.

SUMMARY OF RESULTS

An experimental investigation was conducted in the Lewis Research Center 8- by 6-Foot Supersonic Wind Tunnel to compare the effects on discharge coefficient of venting gaseous helium and nitrogen into a free stream. The test was conducted from Mach 0.60 to 1.57 with the vent mounted in a flat plate. The plate was strut mounted to the tunnel ceiling at a 0 angle of attack. The gases were discharged through a 2.54-centimeter (1.00-in.) diameter, 4.049-centimeter (1.594-in.) thick vent located on the underside of the plate. The boundary-layer thickness to vent diameter varied from 1.34 at $M_0 = 0.60$ to 0.55 at $M_0 = 1.37$. The mass flow ratio varied from 0.03 ($M_0 = 1.57$) to 0.95 ($M_0 = 0.60$).

The following observations were made:

1. In general, the vent discharge coefficient for nitrogen was slightly larger than that for helium at the same plenum pressure ratio. But for practical application the difference in discharge coefficient was insignificant.

2. With a constant value of the plenum pressure ratio (local static to plenum pres-

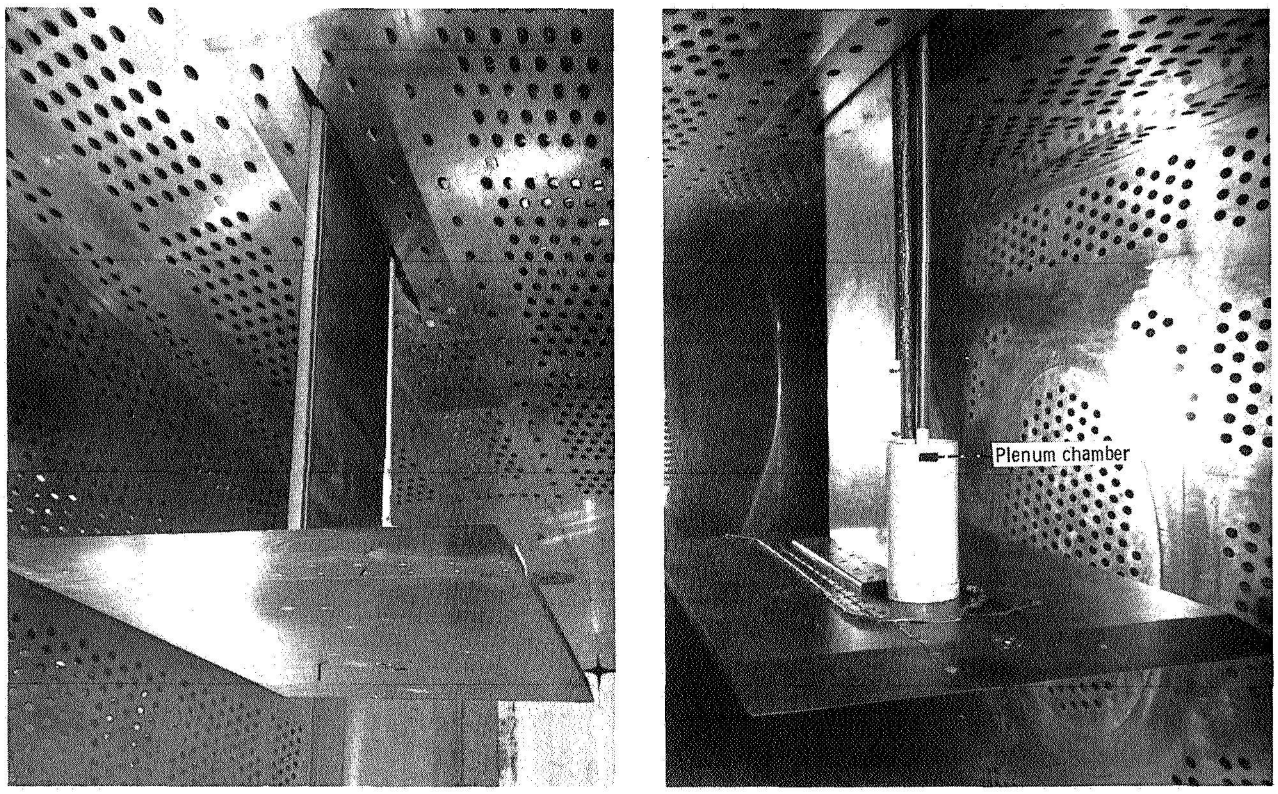
sure) the vent discharge coefficient decreased with increasing free-stream Mach number up to Mach 1.37 and then increased slightly.

3. The vent discharge coefficient increased rapidly with the jet to free-stream mass flow ratio, for values of mass flow ratio less than 0.15.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 7, 1973,
501-24.

REFERENCES

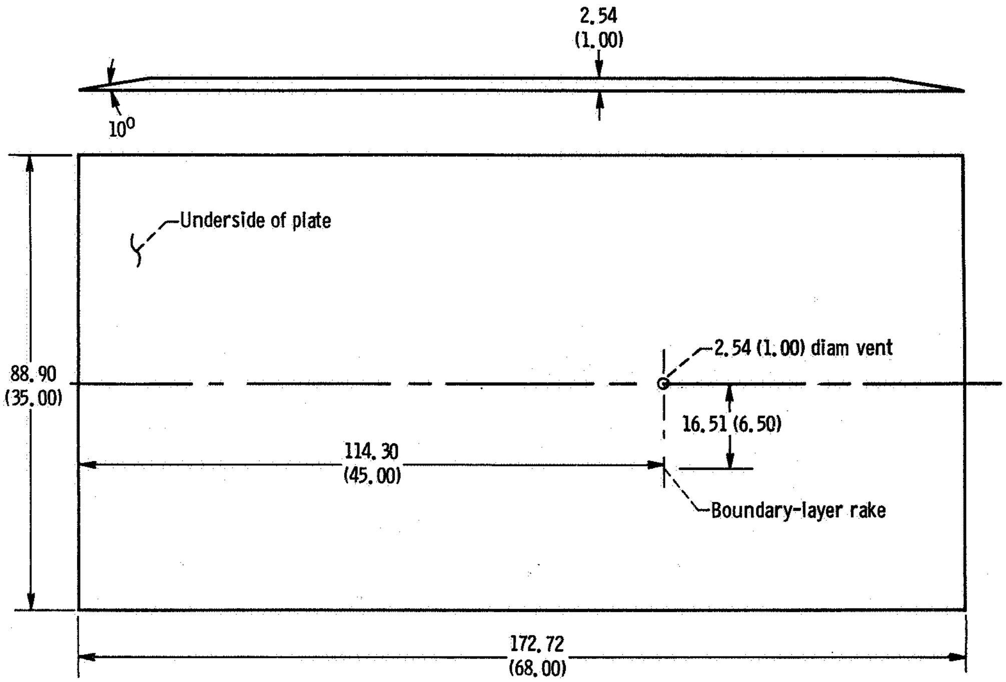
1. Vick, Allen R.: An Investigation to Determine the Discharge and Thrust Characteristics of Auxiliary-Air Outlets for a Stream Mach Number of 3.25. NASA TN D-1478, 1962.
2. Kalioretenoc, C. A.; Leonor, A. P.; and Frandsen, N. P.: Weight Flow Rates Through Circular Holes in a Flat Plate Immersed in a Subsonic or Supersonic Airstream. NOL-TR-61-125, United States Naval Ordnance Lab., Aug. 8, 1963.
3. Callaghan, Edmund E.; and Bowden, Dean T.: Investigation of Flow Coefficients of Circular, Square, and Elliptical Orifices at High Pressure Ratios. NACA TN 1947, 1949.
4. Struck, H. G.; and Harkins, John A.: Compartment Venting and Pipe Flow with Heat Addition. NASA TM X-53734, 1968.
5. Walters, W. P.; Glasgow, R. W.; and Baker, J. M.: Generalized Gaseous Discharge Characteristics of Flat Plate Orifices. TR-794-8-434, Nortronics (NASA CR-98482), 1968.
6. Ramsey, P. E.: Flow Characteristics of Orifices for Venting Launch Vehicle Compartments. In Research Achievements Review. Volume 3: Aerophysics Research at Marshall Space Flight Center, NASA TM X-53799, 1968, pp. 25-34.
7. Compressed Gas Association, Inc.: Handbook of Compressed Gases. Reinhold Publ. Corp., 1966.
8. Anon.: Compartment Venting: Space Vehicle Design Criteria. NASA SP-8060, 1970.



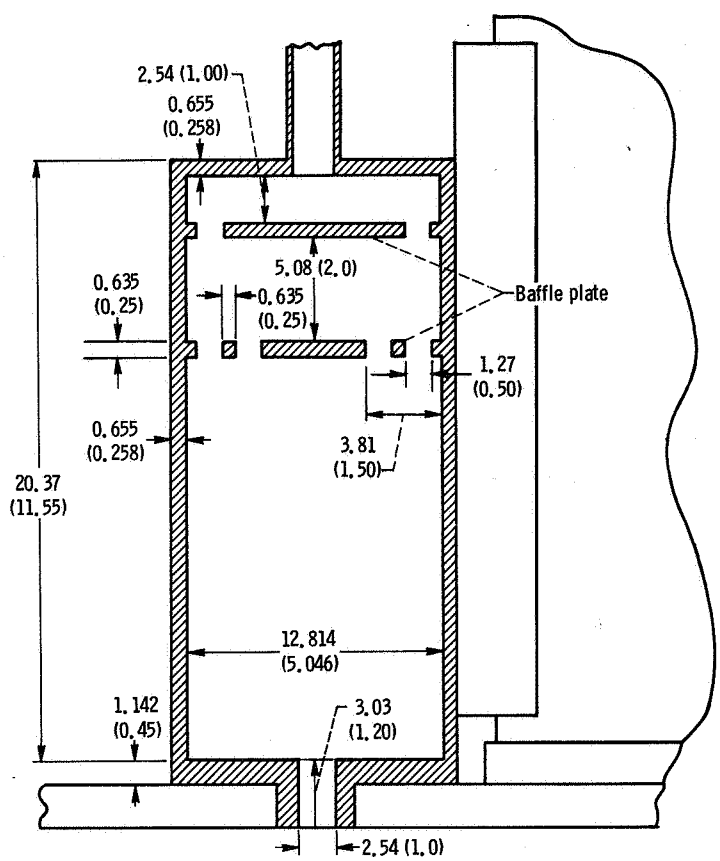
(a) Three-quarter front view.

(b) Three-quarter aft view.

Figure I. - Boundary-layer plate installation in 8- by 6-foot Supersonic Wind Tunnel.



(a) Details of boundary-layer plate.



(b) Details of plenum chamber.

Figure 2. - Details of the model geometry. (All linear dimensions are in cm (in.).)

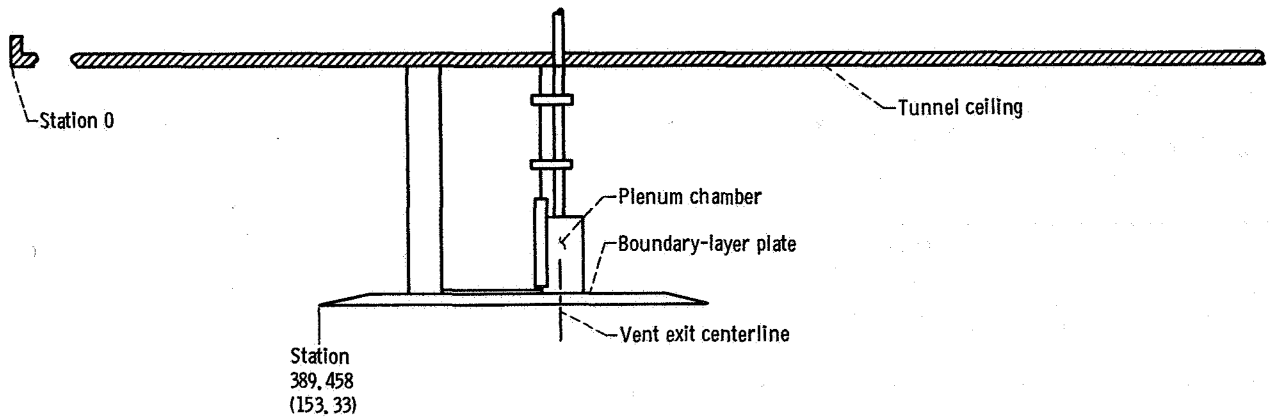


Figure 3. - Boundary-layer plate and plenum chamber installation in 8-by 6-Foot Supersonic Wind Tunnel. (Dimensions are in cm (in.).)

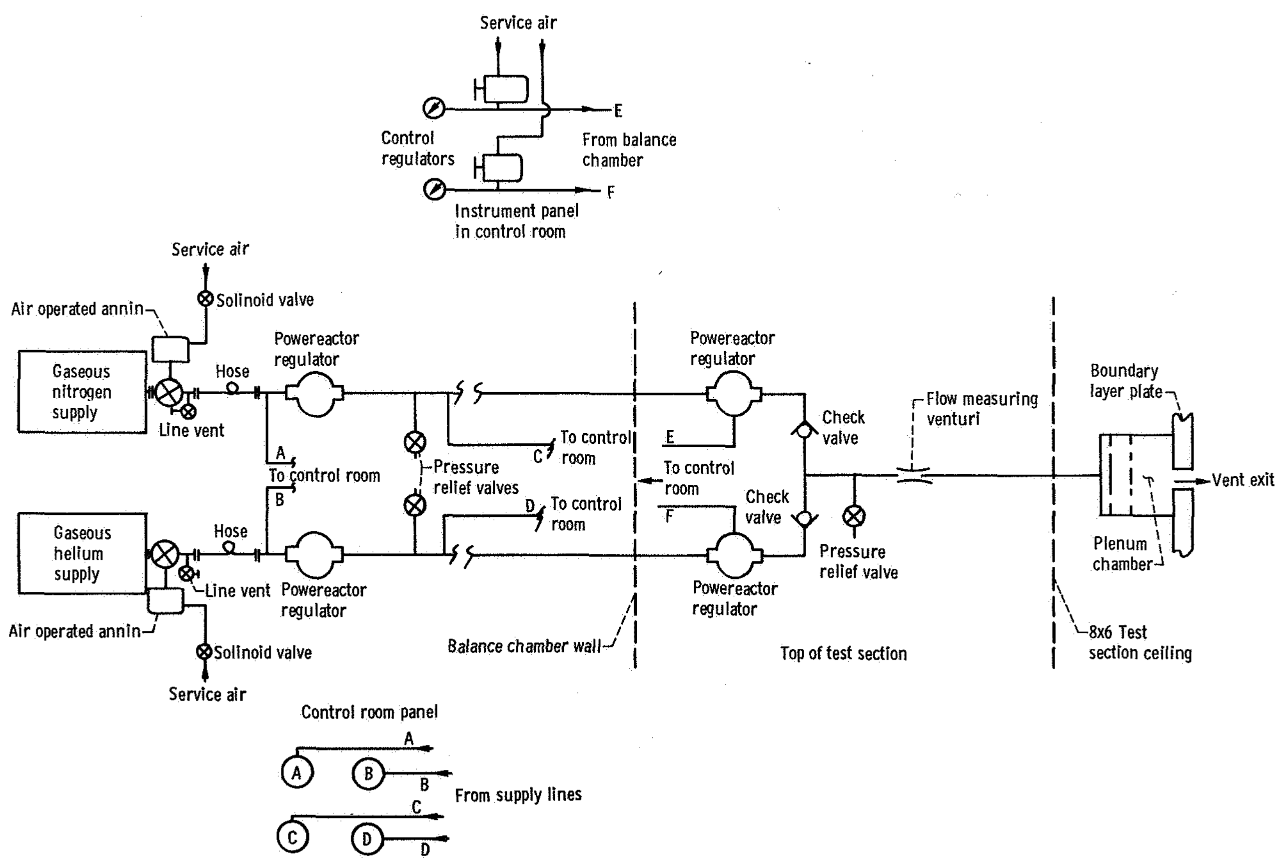
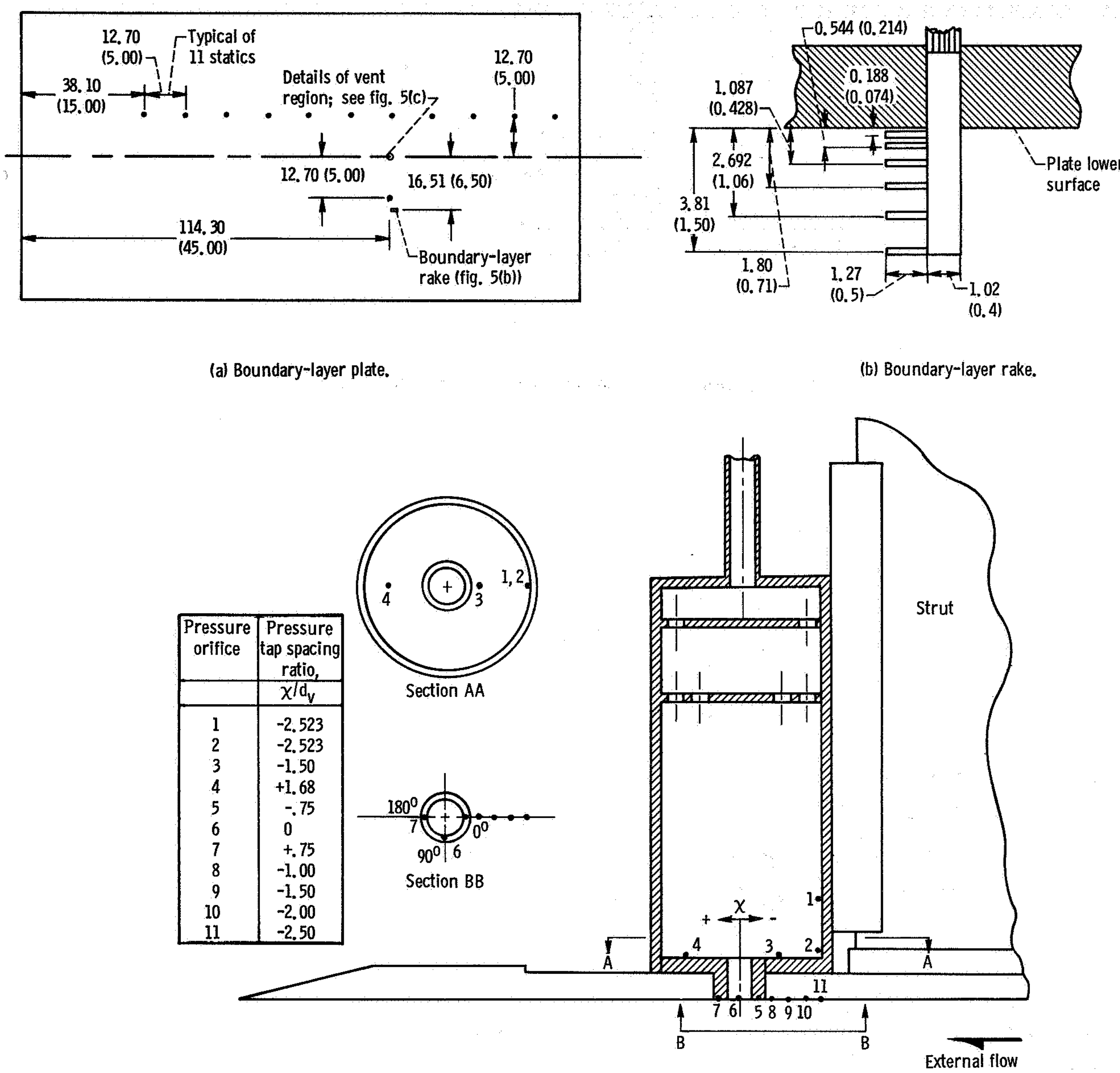


Figure 4. - Schematic of gas flow system.



Pressure orifice	Pressure tap spacing ratio, χ/d_v
1	-2.523
2	-2.523
3	-1.50
4	+1.68
5	-.75
6	0
7	+.75
8	-1.00
9	-1.50
10	-2.00
11	-2.50

(a) Boundary-layer plate.

(b) Boundary-layer rake.

(c) Instrumentation around plenum chamber and vent.

Figure 5. - Details of instrumentation.

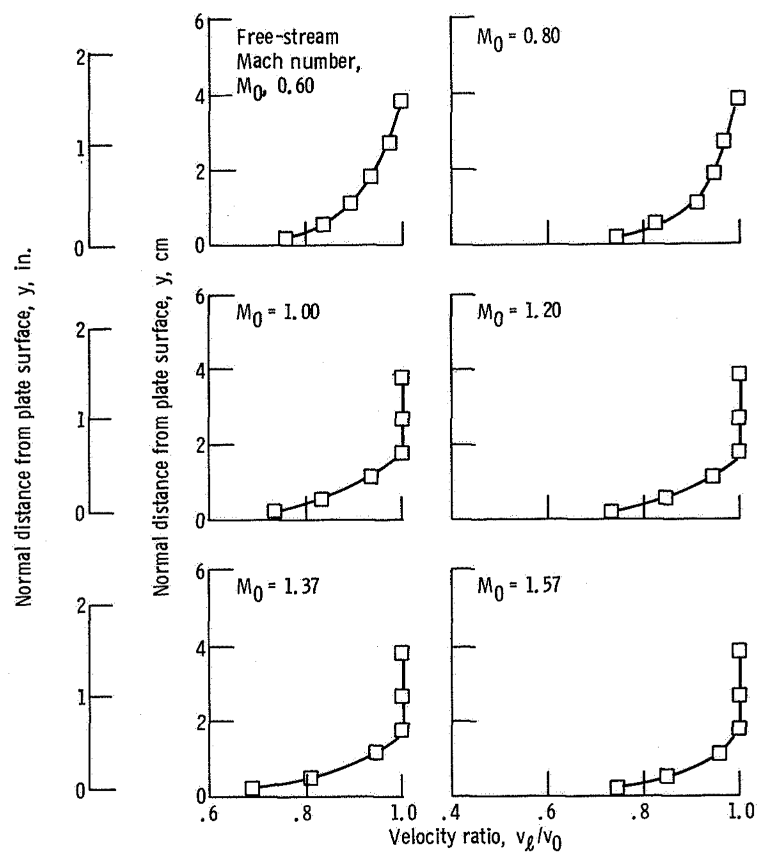


Figure 6. - Boundary-layer velocity profiles.

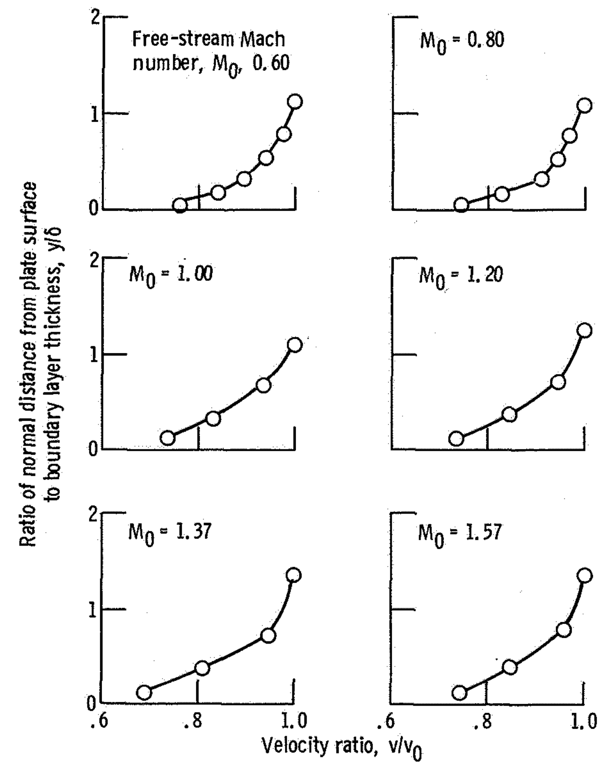


Figure 7. - Nondimensionalized boundary-layer profiles.

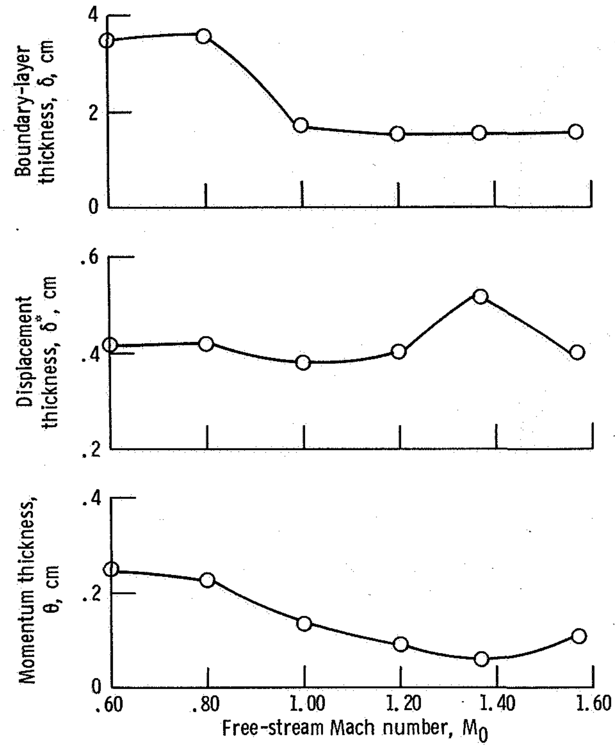


Figure 8. - Comparison of thickness parameters.

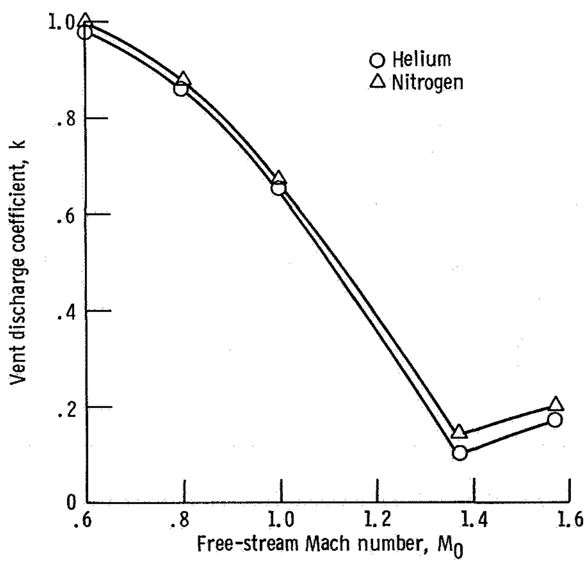


Figure 9. - Effect of free-stream Mach number on vent discharge coefficient, $p_{\ell,3}/p_p = 0.80$.

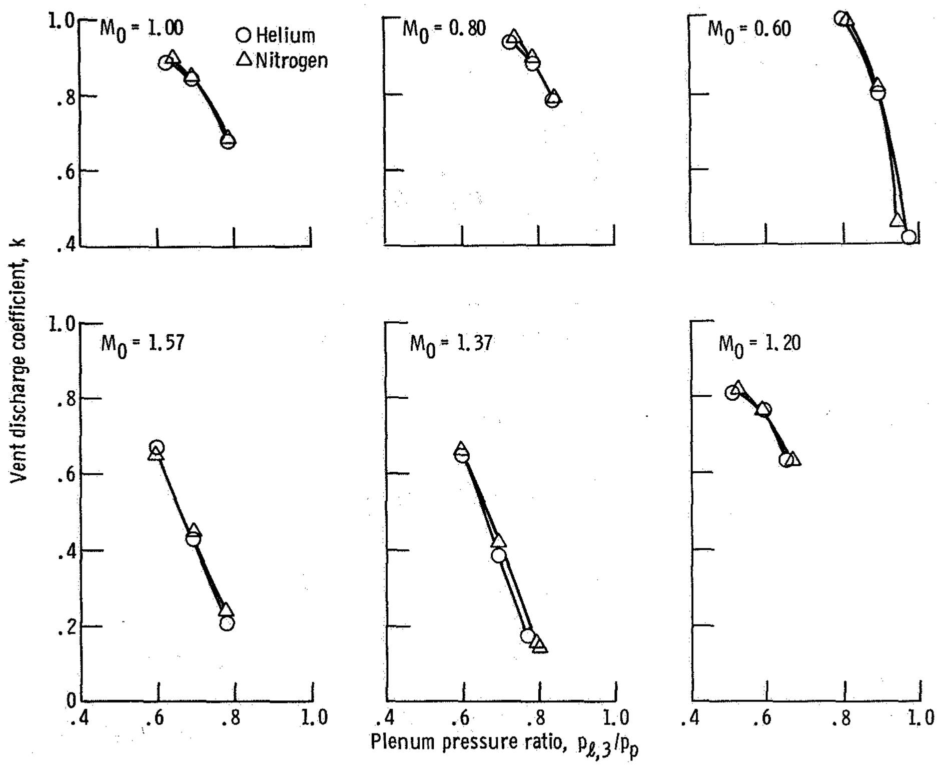
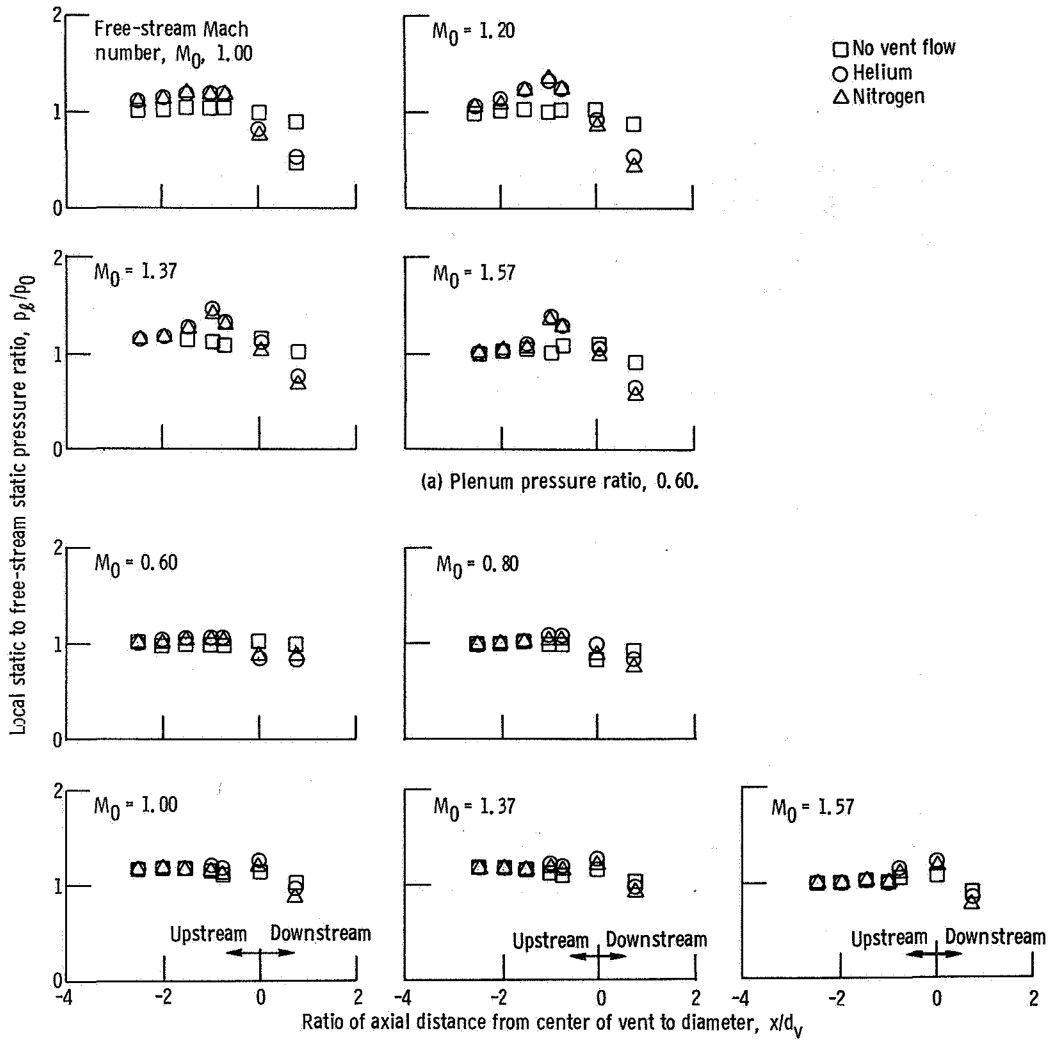


Figure 10. - Variation of vent discharge coefficient with plenum pressure ratio.



(b) Plenum pressure ratio, 0.80.

Figure 11. - Pressure distirubtion in vicinity of vent.

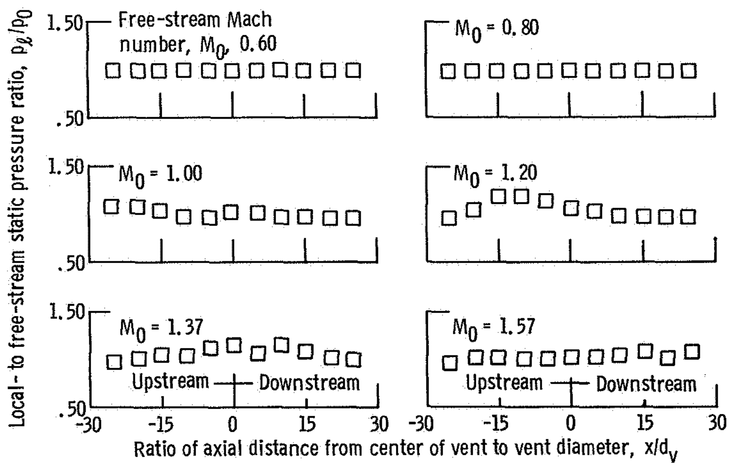


Figure 12. - Plate pressure distributions. 16.51 cm (6.50 in.) off center-line of plate.

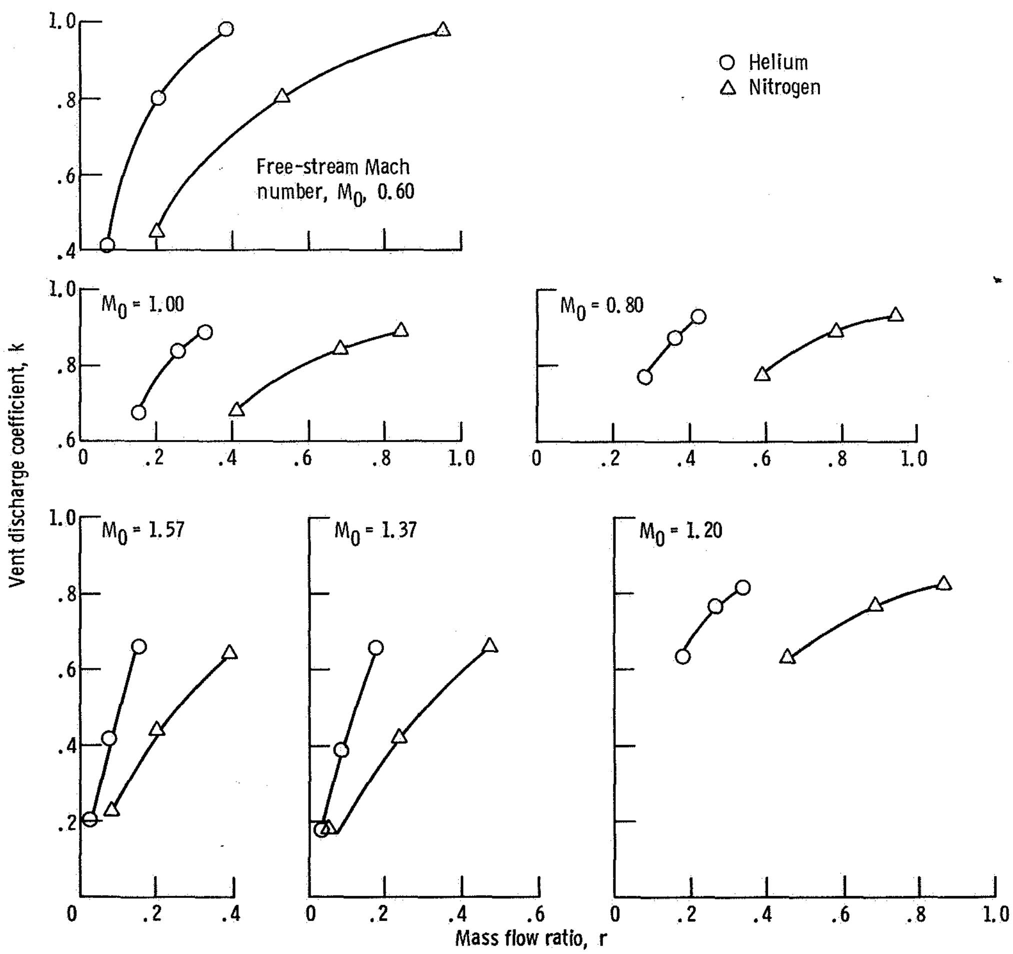


Figure 13. - Variation of vent discharge coefficient with jet-to-free stream mass flow ratio.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

SPECIAL FOURTH-CLASS RATE
BOOK

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
451

U.S.MAIL

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons. Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546